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TECHNICAL REPORT ECOM-01698-5

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

PROGRESS REPORT

by

L. Lesensky - C.R. McGeoch

APRIL 1967

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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Contract DA28-043-AMC-01698 (E)

RAYTHEON COMPANY
MICROWAVE AND POWER TUBE DIVISION
Waltham, Massachusetts

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Technical Report ECOM-0198-5 April 1967

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

Fifth Quarterly Report
15 October 1966 to 15 January 1967

Report No. 5
Contract No. DA28-043-AMC-01698(E)
DA Project No. 7900-21-223-12-00

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Fort Monmouth, N.J.

Sponsored by

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ABSTRACT

Reduction was observed in δ_{max} from 2.3 to 1.4, typically, for sputtered region compared to unsputtered region of electron beam evaporated Al_2O_3 films on Mo substrate.

Two 200 Å CVD-prepared BN films on Mo substrate were evaluated in the Electron Bombardment Vehicle (EBV) and had a δ_{max} of 1.7 to 2.0 which did not deteriorate under electron bombardment at 0.5 A/cm^2 and 1.2 kv for 8 hours.

A 98 + % beryllium sample was evaluated in the EBV. δ_{max} was approximately 4.0 and did not deteriorate during 80 hours of electron bombardment at 0.5 A/cm^2 and 1.2 kv. Indication of δ increases due to O^+ bombardment was observed.

The Hot/Cold EBV has been modified and recalibrated.

The QKS1194 crossed-field test vehicle, containing a barium-calcium-aluminate impregnated tungsten cathode, has been completed and is ready for test.

A brief summary of Cold Cathode Materials Evaluation work performed to date under this contract is included.

FOREWORD

Long-life cold cathode studies for crossed-field tubes are authorized by the United States Army Electronics Command, Fort Monmouth, New Jersey, under DA Project No. 7900-21-223-12-00. The work was prepared under the support of the Advanced Research Projects Agency under Order No. 345 and is conducted under the technical guidance of the U. S. Army Electronics Command, Fort Monmouth, N. J. 07703.

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1. INTRODUCTION

The objective of the present cold cathode study program is to achieve long life cold cathode performance for crossed-field amplifiers. This program is being performed for the United States Army Electronics Command, Fort Monmouth, New Jersey, under contract DA-28-043-AMC-01698 (E).

In this study, selected cold cathode materials will be evaluated as to: their secondary emission properties, their ability to withstand environmental factors expected in a crossed-field amplifier, and their crossed-field amplifier performance. Based on the above experimental information and pertinent theoretical calculations, a life prediction chart will be established for a number of cold cathode materials.

The program is divided into two concurrent phases, phase A being concerned with the measurement of various pertinent properties of cold cathode materials outside of the tube environment, and phase B involving the evaluation and life testing of selected cathodes in a crossed-field amplifier.

The first quarterly report of this contract (Technical Report ECOM 01698-1) contains a discussion of the objectives and plans for the over-all program.

2. PHASE A - MATERIALS EVALUATION

2.1 Secondary Emission Measurements. The series of sputtered samples tested in Table I were examined in the Secondary Emission Test Vehicle (SEE).

Table I

Sputtered Samples Examined in SEE

Sample No.	Composition	N^+ Sputtering History
1	500 Å Al_2O_3 on Mo	5 min, 1 ma/cm^2, 1200 volts
2	500 Å Al_2O_3 on Mo	10 min, 1 ma/cm^2, 1200 volts
3	1000 Å Al_2O_3 on Mo	10 min, 1 ma/cm^2, 800 volts
4	1000 Å Al_2O_3 on Mo	20 min, 1 ma/cm^2, 800 volts
5	1000 Å 30% Mo - 70% Al_2O_3 on Mo	22.5 min, 2 ma/cm^2, 1150 volts

All samples were electron-beam evaporated on a molybdenum (Mo) substrate at a deposition temperature of 600°C. The sputtering due to nitrogen ions was done in the Ion Bombardment Vehicle (IBV) and caused depletion of material in a 3/16in. diameter circular area, located on the center of the sample. By visual examination, samples no. 2, 4, and 5 appeared to have been completely eroded in the sputtered region down to the base metal (Mo). Samples no. 1 and 3 presumably still have half the original film thickness remaining.

The observations in the SEE vehicle are summarized in Table II.

Table II

Sputtered Samples SEE Examination Data

Sample No.	After System Bakeout and 30 Minutes @ 400°C on Target	After 30 Minute @ 950°C on Target
1	Target current erratic, gas bursts	No noticeable gas evolution. ave. δ_{max} (sputtered region) $\approx$ 1.35 ave. δ_{max} (unsputtered region) $\approx$ 2.30
2	Some gas but less than no. 1	No gas. ave. δ_{max} (sputtered region) $\approx$ 1.20 ave. δ_{max} (unsputtered region) $\approx$ 2.00
3	Target current erratic, gas bursts, like no. 1	No gas. ave. δ_{max}(sputtered region) $\approx$ 1.70 ave. δ_{max}(unsputtered region) $\approx$ 2.5
4	Similar to no. 2	No gas. ave. δ_{max} (sputtered region) $\approx$ 1.65 ave. δ_{max} (unsputtered region) $\approx$ 2.45
5	Similar to no. 2	Gas released at some spots, not erratic. ave. δ_{max} $\approx$ 2.5 (averaged over both sputtered and unsputtered regions)

The gas bursts were presumably due to the release of nitrogen which had been imbedded in the target during the sputtering process. The apparent lowering of δ in the sputtered region is believed to be due to the injection of nitrogen ions rather than a reduced film thickness as such. With regard to the amount of gas released, note that samples no. 2, 4, and 5 exhibited no gas bursts and were in general less gassy than the partially sputtered films no. 1 and 3. The oxide films released more nitrogen than the Mo substrate films.

Secondary emission scans were taken of all the targets with three scans in the horizontal and three scans in the vertical direction. It was thus possible to obtain a complete secondary emission topography of the target surface. In general, the δ values were more non-uniform on the surface than the original "unsputtered" surface (see Figure 1) probably was. A typical target current scan, taken at V_{Pmax}, through the center of sample no. 1 after the 950°C heating is shown in Figure 2. Scans of primary current were relatively constant as the beam was deflected across the target surface. Figure 2, therefore, reflects the δ_{max} variation. The central sputtered region shows non-uniformity as well as lower δ_{max} than the unsputtered region.

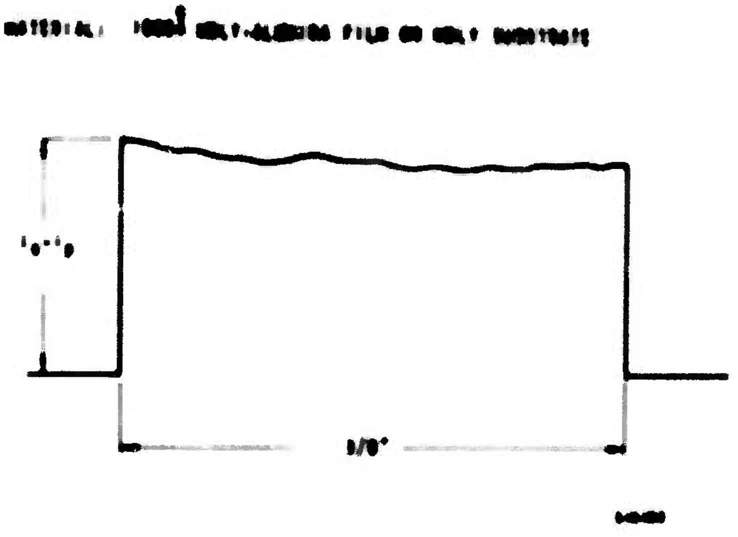

Figure 1   Secondary Emission Scan of 3/8 in. Diameter Target
(Unsputtered Sample)

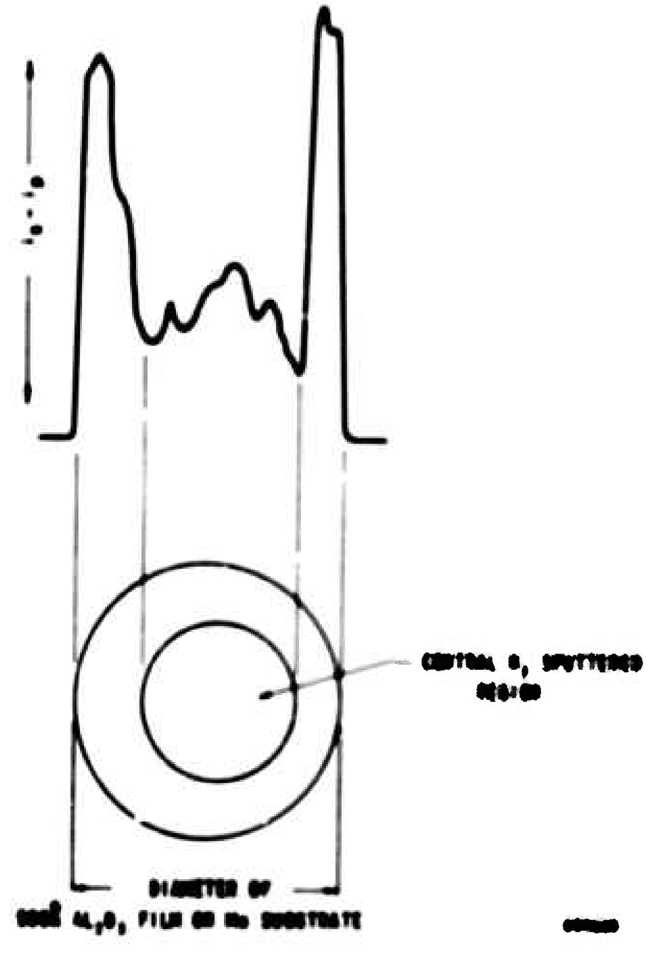

Figure 2   Target Current Scan

2.2 Electron Bombardment Investigations

2.2.1 Boron Nitride (BN) Films. Two BN film samples were prepared and evaluated in the Electron Bombardment Test Vehicle (EBV). These films were formed by chemical vapor deposition techniques to a thickness of 200 Å on a Mo substrate.

The results of electron bombardment at 0.5 A/cm^2 and 1.2 kv are shown in Figures 3 and 4 for BN samples no. 1 and 2 respectively. The secondary emission ratio remained constant for up to 8 hours of bombardment. δ_{max} was between 1.7 and 2.1 and V_{Pmax} was between 350 and 400 volts. These values of δ were much lower than the value of δ_{max} of 4.3 reported in the Third Quarterly Report for an apparently similar BN film. No explanation can be given for the discrepancy. δ values in the EBV may be 15% low as indicated by our previous measurements on platinum. The discrepancy is definitely outside of experimental error. Although no deterioration was observed in the 8 hours of electron bombardment the δ value was low. Further evaluation of BN films will be attempted to obtain electron bombardment evaluation of a high δ BN film.

2.2.2 Beryllium (Be) Samples. A Be disc sample of 98 + % purity had been cut from a sheet by a photoetch process and then diffusion-bonded to a copper surface. This sample is referred to as Be no. 2 as distinguished from Be no. 1 reported on in the Fourth Quarterly Report.

Beryllium sample no. 2 was mounted in the EBV and electron bombarded at 0.5 A/cm^2 and 1.2 kv for approximately 90 hours in two runs. The course of δ_{max}-vs-time is recorded in Figures 5 and 6 for runs no. 1 and 2 respectively. δ_{max} remained relatively constant during bombardment periods in run no. 1, although some increase in δ_{max} was usually observed during the overnight off-periods. It was also noted that the introduction of oxygen to a pressure of 10^{-6} torr had no effect on δ while δ_{max} was approximately 4 during the oxygen treatment.

The data of run no. 2 also indicated no deterioration of δ during electron bombardment periods. A rather interesting phenomenon was observed during this run and is noted on Figure 6 as a δ drift phenomenon. While measuring δ and under voltage conditions for which the anode is more positive than the target, the target current increased gradually while the primary current remained constant. In this way δ_{max} would typically increase from 4 to 5 in about 2-3 minutes. The δ drift described here did not occur with target positive with respect to the anode. Under bombardment conditions (0.5 A/cm^2) the δ would deteriorate from 5 back to 4 in a few minutes and then remain constant. It is supposed that electron bombardment releases oxygen atoms which can be ionized to O^+ by the electron beam and then imbedded in the target. The ion energy would have been ~ 200 volts and it is speculated that at this energy the ion range is small enough to influence δ. A similar process can occur near the cold cathode surface in a crossed-field amplifier (CFA) and serve to enhance δ. In fact it is entirely possible that such a mechanism may be responsible for the discrepancy between secondary emission measurements on Al or Be targets and the effective δ in the CFA. The influence of angle of incidence does not appear to be large enough to explain the observed discrepancies (see the First Quarterly Report).

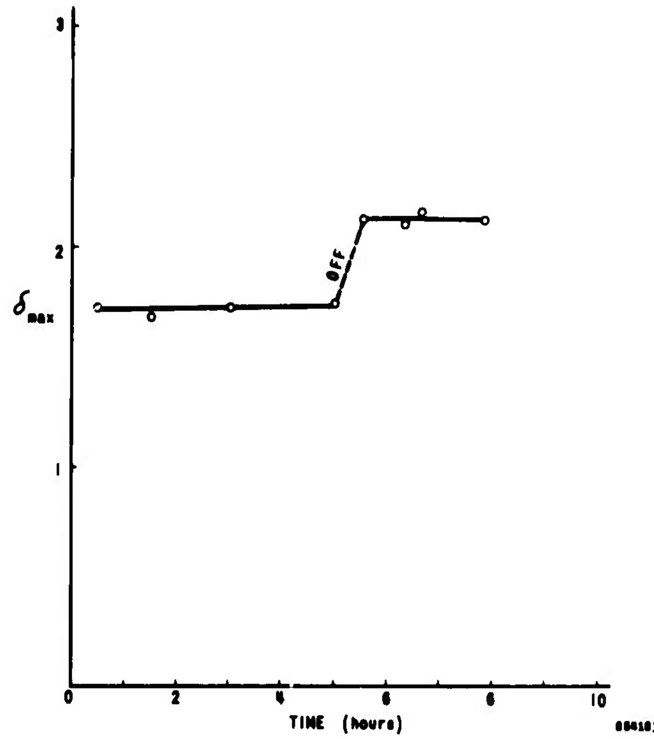

Figure 3 δ_{max} vs Electron Bombardment Time in EBV at 0.5 A/cm^2 and 1.2 kV for 200 Å CVD BN Film No. 1 on Mo Substrate

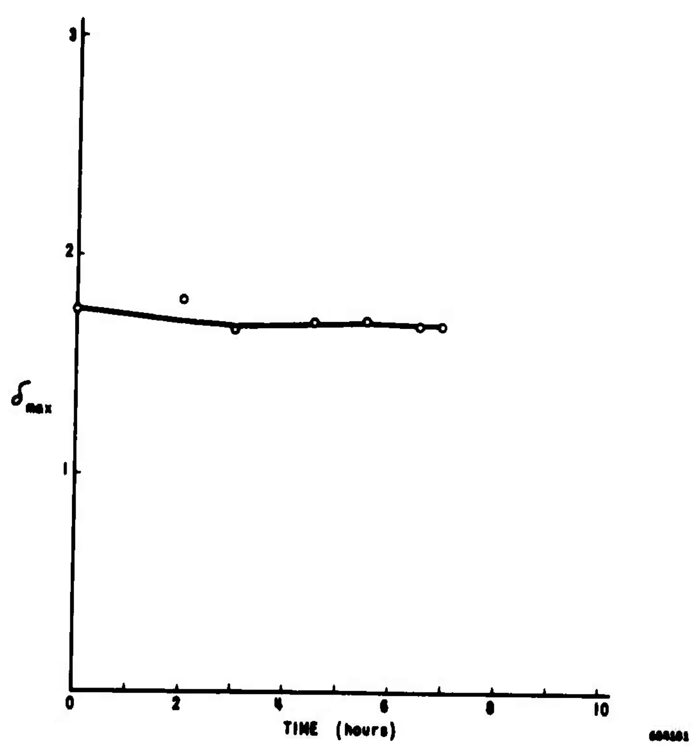

Figure 4 δ_{max} vs Electron Bombardment Time in EBV at 0.5 A/cm^2 and 1.2 kV for 200 Å CVD BN Film No. 2 on Mo Substrate

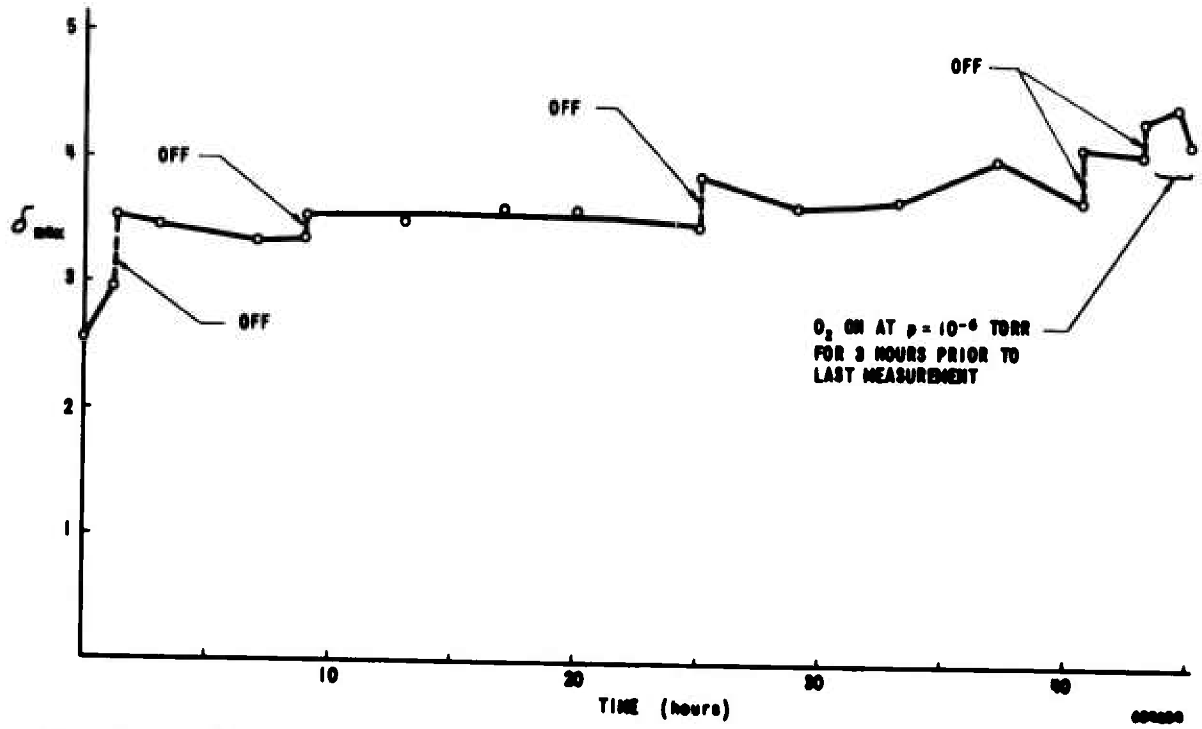

Figure 5 δ_{max} vs Electron Bombardment Time in EBV at 0.5 A/cm^2 and 1.2 kV for Be Sample (Run no. 1)

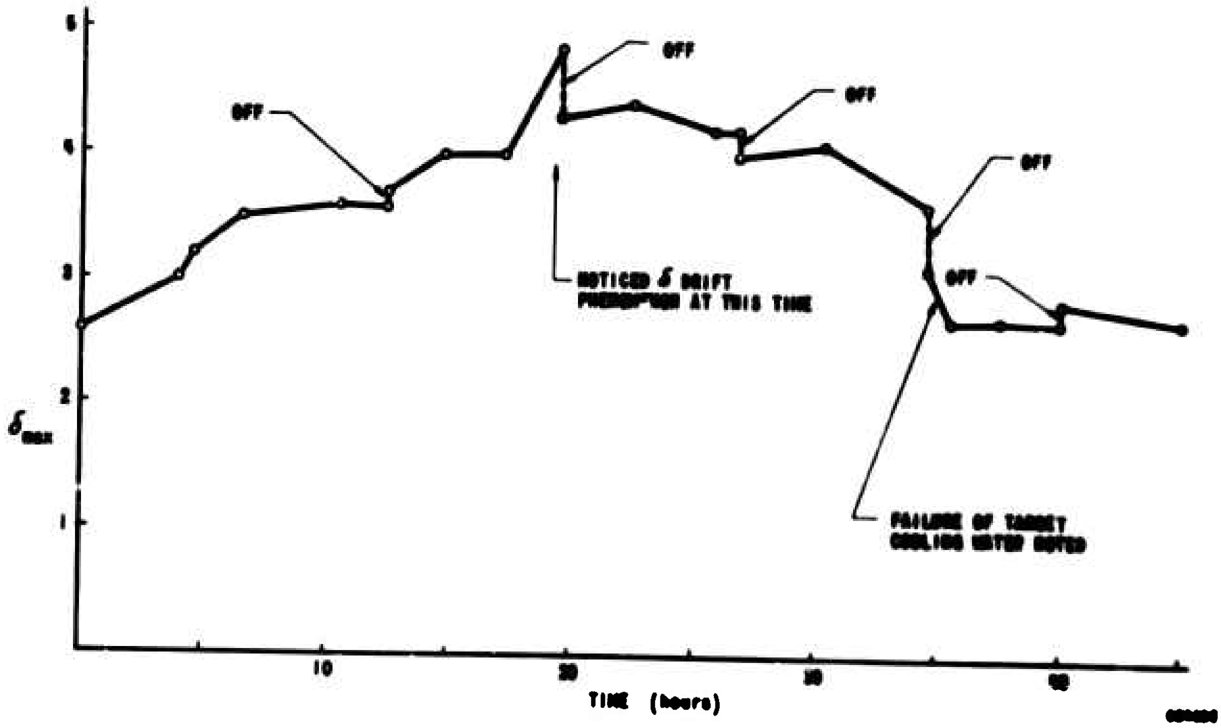

Figure 6 δ_{max} vs Electron Bombardment Time in EBV at 0.5 A/cm^2 and 1.2 kV for Be Sample (Run No. 2)

Near the end of run no. 2, a water failure occurred causing the target to overheat. The δ_{max} decreased to approximately 2.5 and remained at that level under further bombardment. Beryllium sample no. 1 also had a constant δ_{max} of 2.5 under continued bombardment. Further analysis and comparison of Be samples no. 1 and 2 may lead to an understanding of what causes a Be sample to have a δ_{max} of 2.5 rather than 3.5.

2.2.3 Hot/Cold Electron Bombardment Vehicle. At the end of the fourth quarter of this program, the Hot/Cold EBV had failed due to the overheating of some stainless steel component. The vehicle now has been redesigned to avoid this difficulty, with the heater shield modified to achieve more efficiency and to prevent any evaporated material from depositing on the target surface.

The vehicle has been reassembled with an impregnated tungsten target, recalibrated for temperature vs heater power, and will shortly be installed on the EBV vacuum system for evaluation.

2.3 Summary of Phase A (Materials Evaluation) Work to Date. Phase A work has been performed with the following purposes in mind:

(1) To measure δ vs V_p for candidate cold cathode materials.

(2) To evaluate the effect of electron bombardment at 0.5 A/cm^2 on secondary emission ratio.

(3) To observe the effects of ion bombardment on cold cathodes.

We will now outline briefly, in the above order, the results of the work performed.

2.3.1 Secondary Emission (δ) Measurements (in SEE Vehicle).

2.3.1.1 Aluminum

a) Thin oxide layer (~ 25 Å) on surface.

b) δ_{max} in SEE vehicle was approximately 2 while effective value in CFA is typically ~ 6.

c) Measured δ_{max} vs angle of incidence (θ). Found δ_{max} in range 2.0 to 2.6 for θ variation 0° to 70°. This is insufficient to account for the discrepancy.

2.3.1.2 Alumina (100 Å - 1000 Å) Films on Molybdenum Substrate

a) Electron-beam evaporated Al_2O_3 films on Mo substrate.

b) The use of a Mo substrate allows for heating to achieve higher degree of crystallinity and thus higher δ (in comparison with Al_2O_3 on Al).

c) δ_{max} ~ 5, independent of film thickness in range 100 Å - 1000 Å.

2.3.1.3 Molybdenum-Alumina Films on Molybdenum Substrate

a) Electron beam evaporated films.

b) Purpose of Mo is to make thick films conducting to allow for current transmittal. Thick films mean long sputtering life.

c) Most significant parameter of film preparation is substrate temperature during deposition.

d) Agglomeration of Mo caused reduction in δ_{max} from 3.5 (deposition temperature = 600°C) to 1.8 (deposition temperature = 1100°C whereas composition variation of 10% to 30% of Mo resulted in δ_{max} variation only in range 3.5 to 4.0.

2.3.1.4 Barium Calcium Aluminate Impregnated Tungsten

a) δ_{max} is 1.6 to 2.0 before activation.

b) δ_{max} rises to a value of 4.5 after continuing activation at 1050°C, then decreases to a value of 3.0, and then levels off.

2.3.1.5 Nickel Cermet

a) δ behavior due to thermal activation similar to impregnated tungsten.

b) Maximum value of $\delta_{max} \sim 6$.

c) δ_{max} levels off at ~ 3.

2.3.1.6 Semiconducting Diamond (elemental semiconductor)

a) $\delta_{max} \sim 2.3$.

b) Would not evolve atoms due to electron bombardment dissociation.

2.3.1.7 Semiconducting Compounds (non-oxidic)

a) Would evolve orders of magnitude fewer atoms than an oxide due to electron bombardment dissociation mechanism.

b) δ_{max} of GaAs was 3.5.

c) δ_{max} of CdS was 2.0.

d) δ_{max} of CdTe was 1.75.

2.3.1.8 $Ti_{14}Ni_{48.5}Si_{37.5}$

a) Refractory, intermetallic compound, possibly semiconducting.

b) δ_{max} was 1.95.

2.3.1.9 Boron Nitride Films on Molybdenum Substrate

a) Non-oxidic, large gap material.

b) δ_{max} of one sample (200 Å CVD preparation) was 4.3.

c) δ_{max} of 2 additional (similarly prepared) samples were in range 1.7 to 2.0 (measured in EBV which might be ~ 15% low).

2.3.2 Electron Bombardment Effects (in EBV)

2.3.2.1 Molybdenum-Alumina Films on Molybdenum Substrate

a) δ_{max} of 3.6 could be maintained in a 500 Å Mo-Al_2O_3 film by an O_2 partial pressure of 6×10^{-7} torr during electron bombardment at 0.5 A/cm^2 and 1.2 kv.

b) Without O_2, deterioration occurred typically from δ_{max} of 3.8 to 3.2 in 3 hours.

2.3.2.2 Beryllium

a) Two samples of 98 + % purity were used.

b) Sample no. 1 — with electron bombardment at 1 A/cm^2 and 1.2 kv, δ_{max} deteriorated from 3.5 to 2.5 in 2.5 hours and remained constant for 16 hours. 10^{-5} torr oxygen did not cause recovery.

c) Sample no. 2 — δ_{max} stayed at ~ 4.0 with electron bombardment at 0.5 A/cm^2 and 1.2 kv, p = 10^{-8} torr. δ drift phenomenon observed. (described in Section of this report); indicates δ increase due to O^+ implantation.

2.3.2.3 Chemical-Vapor Deposited Boron Nitride Films on Molybdenum Substrate

a) Two samples 200 Å BN film for EBV prepared by chemical vapor deposition technique (CVD).

b) δ_{max} ~ 1.7 - 2.0.

c) No deterioration from this value under electron bombardment at 0.5 A/cm^2 and 1.2 kv.

2.3.3 Ion Bombardment Effects

2.3.3.1 Alumina Films on Molybdenum

a) Electron beam evaporated films.

b) Sputtering of 500 Å and 1000 Å films with N_2 indicated yields of 0.015 molecules/ion at 0.8 kv and 0.017 molecules/ion at 1.2 kv.

c) These films, when half eroded by sputtering, had δ_{max} (in SEE vehicle) of ~ 1.4 in sputtered region and δ_{max} of ~ 2.3 in unsputtered region of same sample.

2.3.3.2 Platinum. Sputtering with N_2 had no observable effect on δ (SEE vehicle).

2.3.3.3 Molybdenum-Alumina Films on Molybdenum. Estimated Al_2O_3 sputtering yield was 0.007 molecules/ion for N_2 at 1 ma/cm^2 and 650 volts.

2.3.3.4 Barium Calcium Aluminate Impregnated Tungsten

a) Sputtering with N_2 for 2 hours at 2 ma/cm^2 and 1.8 kv caused a significant amount of falling out of tungsten particles.

b) These sputtered samples showed a reduction in δ of approximately 10% by comparison of sputtered and unsputtered regions of same sample.

2.3.3.5 Nickel Cermet. Sputtering using N_2 at 2 ma/cm^2 and 2 kv for 1-2 hours caused δ reduction by approximately 10% by comparison of sputtered and unsputtered regions of same sample.

2.3.4. Conclusions. The following conclusions may be drawn from Phase A (Materials Evaluation) work to date.

1) Electron bombardment induced dissociation of oxides is the most limiting failure mechanism.

2) Oxygen may be used to suppress the dissociation.

3) The angle of incidence variation of δ is insufficient to explain the discrepancy between δ in the SEE vehicle and effective δ in a CFA for Al or Be cathodes. O^+ implantation, quite possibly, is responsible for increased δ in CFA.

4) Electron beam evaporated films of aluminum oxide have high δ of approximately 5 as for crystalline oxide.

5) Agglomeration of Mo in Al_2O_3 films causes reduction of δ.

6) The most likely cold cathode candidates for CFA's are:

   (a) Al or Be
   (b) Impregnated tungsten
   (c) Nickel cermet
   (d) Doped boron nitride.

2.3.5 Future Work. The planned work in Phase A for the remainder of the present contract is as follows:

1) Evaluation of impregnated tungsten and nickel cermet samples in Hot/Cold EBV at 0.5 to 1.0 A/cm^2 electron bombardment.

2) Evaluation of CVD boron nitride films in EBV at 0.5 to 1.0 A/cm^2 electron bombardment.

3) Modification of Electron Bombardment Vehicle (EBV) to allow for electron bombardment up to 5-10 A/cm^2.

4) Evaluation of Be and Al samples at 5-10 A/cm^2 electron bombardment.

5) Correlation of δ and electron bombardment resistance with structure (by electron diffraction) of thin aluminum oxide films on aluminum.

3. PHASE B - CFA TESTING

3.1 Description of CFA Test Vehicles

3.1.1 Introduction. The spectrum of CFA test vehicles which have been or may be used in the present cold cathode study program has recently been reviewed with the contracting agency. These include the L-band QKS1319, the S-band QKS1194, the S-band QKS1397, and the C-band QR1480. Short descriptions of these tubes are presented below in sequence for easy comparison. Each represents different stress levels and environmental factors for cold cathode operation.

To date the QKS1319 has been used to evaluate Pt, Al, Be, and Mo-Al_2O_3 film on Mo substrate cold cathodes. The QKS1194, which has the hot/cold (thermally activated) feature, will be used to evaluate a barium calcium aluminate impregnated cathode. The QKS1397 operates at a much higher stress level than the QKS1319 vehicle for further cold cathode evaluation and life testing.

3.1.2 The L-Band QKS1319. The QKS1319 is an L-band forward-wave CFA which provides 100 kw of peak power at 13.5 db gain over a 100 MHz frequency band. A photograph of the QKS1319 is shown in Figure 7. It operates from a dc power supply at 10 kV, and its cold cathode is pulsed on with rf drive and off with a low energy control pulse. Principal operating characteristics are given in Table III.

Table III

QKS1319 CFA Operating Characteristics

Characteristic	Symbol	Quantity	Units
Frequency (Instantaneous Bandwidth)	f	1250-1350	MHz
Peak Power Output (minimum)	p_o	100	kw
Average Power Output (minimum)	P_o	3000	W
Pulse Width	t_p	250	μs
Gain (minimum)	A	13.5	db
Operating Voltage	E_b	10	kV dc
Operating Current (nominal)	i_b	22	a

The tube "package" contains tube, magnets and an outer shell which serves as flux return path and also provides magnetic shielding. The rf couplings mate with standard EIA coaxial lines.

The QKS1319 was under development during the first 12 months of the cold cathode study project and low and high average power versions of this tube have been used for all Phase B secondary emitter evaluation to the present. The use of an oxygen source in a CFA for long-life secondary emitter enhancement was first evaluated in a QKS1319 test vehicle.

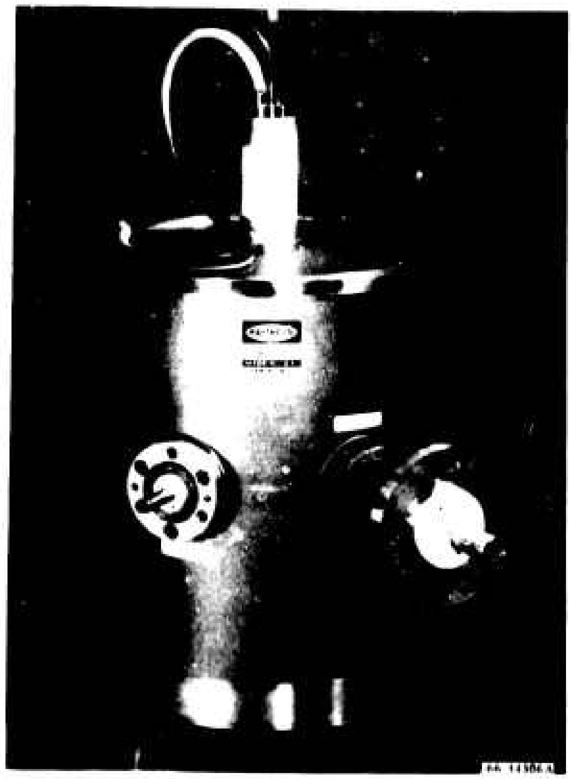

Figure 7 QKS1319 L-Band CFA

3.1.3 The S-Band QKS1194. The QKS1194 is an S-band backward-wave CFA employing a double-strapped vane Amplitron slow-wave structure. A photograph of the packaged tube is shown in Figure 8. The tube provides 1 Mw peak, 15 kW average power output over the range 2800 - 3200 MHz. It also features interchangeable cathode heater and coolant assemblies for the initial activation and operation of its thoria - impregnated tungsten secondary emitter. This feature makes it readily adaptable as a vehicle for evaluating that class of cold secondary emitters which must be thermally activated before tube aging and processing. It operates cathode pulsed at 50 kv and 30 amperes peak with a mean peak current density of 2-3 amperes/cm^2.

3.1.4 The S-band QKS1397. The QKS1397 is the final stage of an S-band forward-wave amplifier chain comprised of three Raytheon tubes. Both the driver CFA (QKS1396) and the QKS1397 have reached the final stages of development. The major performance goals of the QKS1397 have largely been achieved. Electrical performance is given in Table IV.

Table IV

QKS1397 CFA Operating Characteristics

Characteristic	Symbol	Quantity	Units
Frequency (Instantaneous Bandwidth)	f	3135-3465	MHz
Peak Power Output (minimum)	P_o	1000	kw
Average Power Output (minimum)	P_o	4000*	W
Pulse Width	t_p	15	μs
Gain (minimum)	A	16	db
Operating Voltage	E_b	28	kV
Operating Current (nominal)	i_b	80	a

* Limited by present power supply

This forward-wave CFA provides state-of-the-art electrical performance and severe environmental conditions for cold cathode evaluation. The cathode stress level of approximately 6 amperes/cm^2 can be extended to as much as 8-10 amperes/cm^2 by employing a slightly larger cathode diameter and by increasing the rf drive level. The tube has been developed to a point where test vehicle construction is immediately possible.

3.1.5 The C-Band QR1480. The QR1480 is a C-band forward-wave amplifier feasibility study now in the hardware construction phase. Both the anode and cathode stress levels of the QR1480 exceed those of the QKS1397. The tube has not yet experienced hot test operation and is therefore not presently available for cold cathode test vehicle use.

Figure 8 QKS1194 AMPLITRON

3.2 QKS1194 Test Vehicle Evaluation - Hot/Cold (Thermally Activated) Secondary Emitters

3.2.1 Construction. A modified version of the QKS1194 S-band Amplitron was constructed during this quarter. The heater-flange assembly and the cathode-coolant flange assembly were redesigned to change from original heliarc flange seals to de-mountable rubber "O" ring seals. The new design affords an easier and quicker method for switching between heater activation and cold cathode operation. The exhaust tubulation assembly was redesigned to permit the addition of an oxygen source.

A barium-calcium-aluminate-impregnated tungsten cathode was sealed into the test vehicle and experienced a successful bakeout and exhaust.

3.2.2. Barium-Calcium-Aluminate-Impregnated Tungsten-Cathode - Evaluation Procedures. The impregnated tungsten cathode will be evaluated in the next quarter. Under normal circumstances, emitter activation would occur before applying rf drive, however an attempt will be made to operate and process the emitter with rf drive before activation. If this does not succeed, the cathode water coolant system will be removed and the emitter surface will be activated by the usual heater activation schedule. The coolant assembly will be replaced and low gauss emission current boundary data will be taken during tube processing and aging. The schedule for use of the oxygen source will depend upon cathode performance. A controlled experiment will be conducted in the future to obtain quantitative data concerning the effect of O_2 upon the cold cathode performance of impregnated type emitters.

3.3 High Average Power Life Test Facilities.

Installation of a QKS1319 high-average-power life test station was completed during this quarter. Parts for the construction of the life test vehicle were ordered, but work on this test vehicle was discontinued to permit concentration on higher stress level QKS1397 CFA vehicles.

3.4 Present Status of CFA Testing.

Platinum and various metal-oxide-film type cathodes have been evaluated in specially constructed L-band CFA test vehicles with QKS1319 basic design at low and high average power levels. The aluminum and beryllium metal oxide film emitters have been evaluated in a test vehicle with cathode-segment type control electrode. ECB's (emission current boundaries) for these emitters have been measured and interpreted in previous reports.

A barium-calcium-aluminate-impregnated tungsten cathode has been sealed into an S-band QKS1194 test vehicle for "hot/cold" cathode evaluation and has been successfully processed. The cathode is ready for evaluation testing.

The installation of a CFA test position for cold cathode life evaluation with the QKS1319 L-band forward wave amplifier was completed.

4. CONCLUSIONS

The work of the fifth quarter allows us to draw the following conclusions:

1. N^+ sputtering of alumina films results in a lower δ for the film, which does not recover on exposure to air.

2. δ_{max} for a 200 Å CVD-BN film on a Mo substrate can be as low as 2.0 and as high as 4.3.

3. A beryllium sample can maintain a high δ (3.5 - 4.0) for periods of at least 80 hours under electron bombardment at 0.5 A/cm^2 and 1.2 kv in a vacuum of 10^{-9} torr.

5. PROGRAM FOR NEXT INTERVAL

During the sixth quarterly report period 15 January to 15 April, 1967, the following work is planned.

(1) Complete evaluation of impregnated tungsten cathode in QKS1194 test vehicle.

(2) Construct first test vehicle of QKS1397 type with beryllium cathode and oxygen source.

(3) Further evaluation of BN film samples in EBV.

(4) Complete test of impregnated tungsten sample in hot/cold EBV.

(5) Design, construct modified EBV for 5 to 10 A/cm^2 operation.

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13. ABSTRACT

Reduction was observed in δ_{max} from 2.3 to 1.4, typically, for sputtered region compared to unsputtered region of electron beam evaporated Al_2O_3 films on Mo substrate.

Two 200 Å CVD-prepared BN films on Mo substrate were evaluated in the Electron Bombardment Vehicle (EBV) and had a δ_{max} of 1.7 to 2.0 which did not deteriorate under electron bombardment at 0.5 A/cm^2 and 1.2 kv for 8 hours.

A 98 + % beryllium sample was evaluated in the EBV. δ_{max} was approximately 4.0 and did not deteriorate during 80 hours of electron bombardment at 0.5 A/cm^2 and 1.2 kv. Indication of δ increases due to O^+ bombardment was observed.

The hot/cold EBV has been modified and recalibrated.

The QKS1194 crossed-field test vehicle, containing a barium-calcium-aluminate impregnated tungsten cathode, has been completed and is ready for test.

A brief summary of cold cathode materials evaluation work performed to date under this contract is included.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Secondary Emission						
Cold Cathode						
Crossed-Field Amplifiers						
Electron Bombardment						
Ion Bombardment						
Thin Films						
Al_2O_3 Films on Mo Substrate						
CVD-BN Films on Mo Substrate						
98 + % Beryllium						
EBV						
O^+ Bombardment						
QKS1194 Crossed-Field Test Vehicle						
Materials Evaluation Summary						

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